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ABSTRACT : *The question of rationality in front of the diversity of knowledge practices*

The diversity of knowledge practices that correspond, in different cultural systems, to what we call «science» in our own (or owns), asks the question not only of knowing whether these sciences or knowledges may be compared and how, but also, more deeply, that of the type of rationality which underlines them. We intend to situate some aspects of the latter question from a methodological point of view, philosophical as well as historical. We show, in particular, that history of science provides in this respect elements, by permitting to recognize, under the transformations of the contents of knowledge, correlative transformations of rationality itself that make possible to discover, to recognize and to assimilate new knowledges.

RESUME : *La question de la rationalité face à la diversité des pratiques de connaissance*

La diversité des pratiques de connaissance qui correspondent, dans des systèmes culturels différents, à ce que nous appelons «science» dans le nôtre (ou les nôtres) pose la question non pas seulement de savoir si ces sciences ou connaissances sont comparables et comment, mais aussi, plus profondément, celle de la rationalité qui les sous-tend. On se propose de situer quelques aspects de cette dernière question d'un point de vue méthodologique, tant philosophique qu'historique. On montre, en particulier, que l'histoire des sciences fournit à cet égard des éléments, en laissant discerner, sous les transformations des contenus de connaissance, des transformations corrélatives de la rationalité qui permettent de découvrir, de reconnaître et d'assimiler les connaissances nouvelles.

RESUMEN : *La cuestion de la racionalidad frente a la diversidad de las practicas de conocimiento.*

La diversidad de las prácticas de conocimiento que corresponden, en los diferentes sistemas culturales, a lo que nosotros llamamos de «ciencia» en el nuestro (ou los nuestros) lleba la cuestion no solamente de saber si esas ciencias o conocimientos son comparables y como, pero también, más profundamente, la cuestion de la rationalidad que los sobtiende. Queremos, en esa comunicación, situar algunos aspectos de esta última interrogación de un ponto de vista

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metodológico, filosófico así como historico. Mostramos, particularmente, que la história de las ciencias fornece elementos a ese respecto, dejandonos dicernir, bajo las transformaciones de los contenidos cognitivos, transformaciones correlativas de la rationalidad que permiten descubrir, reconocer y asimilar nuevos conocimientos.

1. INTRODUCTION. KNOWLEDGE, SCIENCE, RATIONALITY, AND CULTURAL SYSTEMS

The diversity of the knowledge practices and of the systems of thought that correspond, in different cultural systems, to what we call science in our own (or our owns), asks the question not only of knowing whether these sciences or knowledges may be compared and how, but also, more deeply, that of to which type of rationality do they correspond. The problem of rationality has been generally considered by philosophy and history of science from the analysis of scientific domains defined more or less in the way we conceive them today. In the twentieth century, emphasis has been put by philosophy on the criteria that allow to state that a given knowledge is rational, and these criteria are practically identified with those of scientificity (verificationism for meaning «à la» Carnap, faillibilism «à la» Popper, etc.), being admitted, however, that there are different criteria for each domain of science, and rationality is not uniform[1]. It is admitted also, since Kantian philosophy, that a different type of reason should be invoked respectively for knowledge (theoretical or pure reason) and for action (practical reason, referred to ethics for Kant, to which other can be added such as technical and decisional reasons). Considerations from historical epistemology have shown that rational knowledge grows through reorganizations and these latter imply modifications of the conceptions of the rational frame itself[2].

In this sense, Jean Ladrière speaks of the "polymorphism of reason" and of its "intrisic historicity"[3]. Let us note that the idea that reason itself and not only the contents of knowledge are evolving has to be brought back to Hegel, i.e. to a philosophy that was not directly connected with exact science[4]. But it is in science that one generally thinks to be able to identify these evolving forms, because science is closer than any other human activity to a direct use of reason, and is often accompanied by a reflexive and conscious thought about it. As Ladrière says again : "Reason builds itself in the practices in which it recognizes

[1] See, for example, among significant and relatively recent studies that deal explicitly with rationality and science : Newton-Smith [1981], Radnitsky and Andersson [1978].

[2] Gaston Bachelard has insisted on this, calling history of science upon the task to grasp "rationality in the making", and asking from epistemology to "put systematically reason and scientific object into a dialectics of cooperation" (Bachelard [1949], p. 9). And, as he wrote : "The intentionality of applied rationalism keeps in reserve the possibility of rectifying itself" (*ibid.*, p. 10). As for his quoted book, he analyses in it various "regional rationalisms" (or disciplinar ones) from the recent history of physics.

[3] Ladrière [1999]. See also Ladrière [1977].

[4] Granger [1955].

itself and it discovers itself in the process of its elaboration. Science plays an important paper in this process of self-constitution of reason. From the form of rationality it uses essential features of reason are revealed, and by reflecting about these one find in them data of a peculiar significance"[5].

But the fact that science as we know it today is a good analyser for the characteristics of rationality does not mean that it exhausts the forms rationality can take, and neither that it allows to exhibit clearly all the components of these rationalities, for reason itself is implied in its own judgements about reason, in its self-understanding, and some opacity will therefore always remain in its own grounds[6] as, indeed, in any search for foundations of knowledge. For this reason and because it is an evolving entity, reason is not closed inside itself. It is open to some necessity that escapes it, which means that we don't know how to characterize reason in a fully analytical (and predictive) way, although we may know how it works through its use. Reason is a function of the mind, and capacity to it is underlying, in a way or another, thoughts and actions, the conscious ones (which does not mean, indeed, that thoughts and actions are not led also by other instances such as desires, passions, imagination, the subconscious…), and possibly many unconscious ones as well, although indirectly, through a complex network whose exact knowledge stands outside of our reach. On another hand, reason escapes us in that sense that we do not master its definition nor the direction toward which it impulses us with respect to new and future uses of it, and to our future conceptions of it as well.

For all what precedes, it appears highly wishable not to restrict our study of rationality inside the field of modern and present sciences, and to consider other conditions of its use and other circumstances of its being constituted. We shall however restrict ourselves here to considerations on rationality and «positive» knowledge. From this perspective, our conception of present science itself will be somewhat enlarged and, when considering cases in it, and particularly cases of creative activity, we shall perhaps be more sensitive to a diversity in the ways of thinking and reasoning of scientists, than we were before, and above all if we have been trained in a context where scientific statements were considered as needing "rational reconstructions" after having been invented in order to become truely scientific[7].

Rationality can actually be found in any cultural system related to knowledge, even when this knowledge looks essentially empirical, and even when it is narrowly tighted with other kinds of representations and beliefs. As to the first consideration, we may assert that any empirical knowledge is embedded into a

[5] "La raison se construit dans les pratiques en lesquelles elle se reconnaît et elle se découvre elle-même en se construisant. La science joue un grand rôle dans ce processus d'autoconstitution de la raison. Dans la forme de rationalité qu'elle met en œuvre se révèlent des traits essentiels de la raison, qui s'imposent à la reflexion comme des données particulièrement significatives" (Ladrière [1999]).

[6] Ladrière states this nicely in his quoted article (Ladrière [1999]).

[7] This being the «received» view from logical positivism and empiricism, shared after them by many philosophers and even historians of science, with the distinction between the contexts of "discovery" and of "justification" proposed by Hans Reichenbach (Reichenbach [1938]) and widely admitted from Karl Popper (Popper [1935, 1972]) to Imre Lakatos (Lakatos [1978]) and Thomas Kuhn (Kuhn [1962, 1977]).

system of significations that links it to some rationality. As for the second one, our assertion can be argumented by considering (although we shall do it very briefly here) various situations of knowledge and the corresponding rationalities in different cultural systems of the past or of the present times. We shall begin by evoking different and heterogeneous cultures and their respective related forms of rationality ; we shall then make our path inside the given particular cultural direction that is related with «modern» and «contemporary» science, focusing our attention on the question of the constitution of a given scientific field through a variety of elaborations and endeavours that can be considered as equally valuable from the point of view of rationality.

We shall propose, on the whole, that the diversity of and the changes in the forms of the rationalities that are actually at work in the scientific enterprise must be considered as a universal factual (historical) circumstance, that characterizes human knowledge in general and its conditions of possibility and of effectiveness. We might then be able to understand more clearly how rationality is the frame required by thought to make the world intelligible ; and to grasp something of the means through which it is adapted by the mind to this effect, when trying to assimilate the data or the elements that are presented to it or which it has been led to discover. The diversity and changes in rationality are directly related with the various possible ways to make the world intelligible in given intellectual and cultural contexts and to respond to the demand of a better intelligibility for it. This by no means entails any relativism in a radical sense, for rationality implies the possibility of communication, hence of comparison, and changes of rationalities operate through the capacity of these to grow[8].

2. CONSIDERING DIFFERENT CULTURES : COMPARISONS, RELATIONSHIPS, DIALOGUES

All human societies have and have had cultural life, realizations and world-views that include knowledge practices and a body of knowledges, taking as a whole or separately the form of a system. In the modern world, the knowledge system has been conceived as self-consistent and as constituting a clearly separable form, called «science», among other components and forms of culture such as art, technique, religion, etc. Different cultures have not had necessarily the same categorizations and separations, and this must be taken into account when we want to compare the different practices and symbolic representations of knowledge in other cultures corresponding to parts of our «science».

In all these cultures, the systems of representation that include knowledge are not closed inside themselves, being necessarily open to the world from where they get their knowledge contents (starting from the environment, which includes the starred sky), and effectiveley also to other cultural and knowledge systems (beginning from those of their immediate neighbours). Anthropology, ethnology, history of civilizations, history of science, teach us with their various voices that such interactions with the world and such exchanges and

[8] I refer to precedent papers of mine dealing with this : Paty [2001 a and b].

transmissions are constant features of the societies among each other, as well as of individual human beings with the world and between themselves. Take botanical, agronomic and medicinal knowledges that are present in any human traditional collectivity and enrooted since the depth of times in secular experience, practices and beliefs. Take also the sophisticated geometrical drawings or material figures of artwork, pottery, weaving, basketwork, body painting, exhibiting a refined knowledge on symmetries, as encountered in many indigenous cultures around the world, and which are at present an object of study of ethnomathematics[9]. We may evoke as well the complex matrimonial and exogamic relationships in indigenous ethnies, that exhibit, according to Claude Lévi-Strauss[10], structural features of the groups considered in mathematics : which reveals a practical ability to implicit deep mathematical thinking, even if it remains unconscious to the actors themselves, as an expression of the structure of mind confronted with a complex of conditions.

Among the common features that are responsible for this capacity of men in society to observe, to make symbolic representations, to act consciously on the world, one is the capacity of reasoning, that is to think, accordingly to what we call reason, that is "equal in all human beings", as Descartes wrote[11]. And there is effectively no doubt that reason is present in all men and in all cultures, for without it they would not have survived, produced and developed material and cultural realizations such as those as we can witness in the present and also, for some of those of the past, partially preserved, which we can observe and try to understand, as meaning for us and as meaning (a different one) for them.

But the forms of rationality at work in these knowledge practices and representations are very different from one culture to another one. Behind the diversity of the knowledges, we find a diversity of the forms of rationality, in geographical space and above all through history. What do these rationalities have in common ? and what does justify us to refer them to a single and common property such as reason (that is, the capacity of reasoning) ?

To fix the ideas, we can take some illustrative historical examples of the diversities of rationalities, which exhibit some fundamental features they have in common, referred to sharing a function, as can be shown from considerations about comparison, relationship, dialogue and exchange. Such a state of things allows us henceforth to speak rightly of them in terms of the same concept of «rationality», although it presents itself under different forms.

Mythical thought, for example, is not outside the frontiers of reason, although it has seldom been explicitly referred to the function of reason and to rationality. In his profound study *The philosophy of symbolic forms*, where he analyses successively language, mythical thought and the phenomenology of knowledge, Ernst Cassirer considers that "myth and scientific knowledge do not differenciate one from the other by the nature and the quality of the categories they

[9] See, for example, Gerdes [2000 a and b].
[10] Lévi-Strauss [1948, 1958]. See the analyse of the structural method in Lévi-Strauss, in particular from his 1948 book, by Françoise Héritier (Héritier [1999]), and the remarks by Emmanuel Terray (Terray [1999]).
[11] Descartes [1637].

use, but by their *modality*"[12]. We can actually refer these categories and their modalities to features of reasoning. Cassirer exemplifies his assertion by mentioning the "modes of connection" used in both forms of thought in order to give "the form of the unity" to the diversity of the tangible world, and he observes that they are the same for both. He explains this from the fact that they are the more general "«forms» of thought and of intuition, constituting the unity of consciousness as such, and henceforth the unity of the mythical consciousness as well as of the pure scientific consciousness"[13]. Further on, he emphasizes that, "abstractly speaking", the "same kinds of relationships, of unity and plurality, of «coexistence», «proximity» and «succession»" rule the interpretations of the world, the mythical as well as the scientific ones.

Cassirer situates the difference, at this categorial level, between mythical and scientific thoughts, in the specific role played, in scientific thought, by the "synthetic judgement", which operates a unification, in the intuition, of the *diverse* through the relationship of the latter's elements, idealized, and thought as such, from their mutual relations, made explicit and formalized. On the contrary, unity and totality, which are most pregnant in mythical thought, are obtained in it through a mere identification of all the elements toward the whole in which they melt. The *wholeness* of scientific thought is conceptual and abstract (it is such that "idealized relations build formally the world according to universal laws"), whereas that of mythical thought is concrete and immediately given, and imaginary at the same time. In Cassirer's analysis, mythical thought in its various states admits only one dimension and one level of being for its relationships ; the part becomes (or is) the whole (instead of representing it), and the substantial relationship (of coïncidence and identification) is thought according to a law of participation (a concept put forward by Lévy-Bruhl[14]). But in its upper versions, mythical thought has been at the origin of scientific thought, explains Cassirer, taking as examples astrology and alchemy as two forms of "the mythical thought of substantial identity" (bringing together different effects that they relate to a unique material cause)[15].

We may wonder whether it is possible to go deeper into the exploration of reason inside components of systems of thought that are generally taken as mythical, but which in some way or other are related to the production of positive knowledge, and which could henceforth be compared with explicitely assumed rationality and possibly converge with it. Let us take shamanic societies as one possible type of examples, considered either far away in time with prehistorical societies, either in contemporary remote contexts[16]. According to the present ethnographic conceptions, shamanism is an objective, anthropological and social, phenomenon that includes a system of representations, of ideas and values,

[12] Cassirer [1923-1929], vol. 2, trad. fr., p. 85.
[13] *Ibid*.
[14] Lévy-Bruhl [1922].
[15] Cassirer [1923-1929], vol. 2, trad. fr., p. 91-92. See also, in this book, the subsequent analyse of myth as a form of intuition, and as a form of life, seen as primary directions for the formation of future scientific thought.
[16] For the prehistorical societies supposedly shamanic, see Clottes, Lewis-Williams [1996]. For shamanic societies of the nowadays, see, for instance, the review by Xavier Ricard (Ricard [2000]).

of symbols and concepts, a body of knowledge about nature with applications, cures of diseases, etc. It involves also an animist thought about nature, which is at the same time irrational and rationally structured.

According to the definition proposed by Roberte Hayamon, shamanism is "a symbolic system founded on a dualistic conception of the world [with] relationships of alliance and exchange with the supra-natural beings that are supposed to govern the natural beings from whom his subsitence depends (…), [with] nature he treats as a partner, which requires from him a personalized art ; this function, a regular one, affords him with a central position and founds the totalizer aspect of shamanism in societies which are, for this reason, called shamanist"[17]. In all these respects, shamanism appears as a religious system among others, in which the knowledge of nature (and of man) is intrisically related with a rational activity, even if it calls also for beliefs in supernatural entities.

In such systems, modifications of knowledge and, possibily, to some degree, of its structure, are observed, through exchanges operated from shamans circulation among themselves from a village to another one, and through the necessity in which shamanic societies are to adapt themselves to the modifications of their environment. In these adaptations, *rational* reflection of the kind we consider as being such (involving relationships of elements through the consideration of their differences) seems to take an important part, witnessing a general aspect of the function of rationality, which is conscious adaptation to external changes[18].

To explore more thoroughly these questions is the project of a young anthropologue, Xavier Ricard, who is presently studying shamanic societies in the altiplano of the Andes mountains of southern Peru, a region where Alfred Métraux did his own research more than half a century ago, but still poorly known[19]. He wants to examine to which extent shamanism is a consistenty body of practices and representations, and corresponds to elaborations and transformations with a rational frame. His inquiry takes as a starting point the following question, a pertinent one about any apparently irrational representation of the world upon which a given society founds itself : "How can beliefs which appear as irrational serve as long lasting foundations to a society ? (…) How can such beliefs go on in time, and be convincing enough to organize, on a wide scale, social relations ?", considering the established social importance of the shaman.

According to Xavier Ricard's approach, shamanism is a mode of religious thinking, and has links with reason which must be studied in a similar way as religious thinkings and traditions have been studied in the West, not restraining oneself to mere sociological or anthropological descriptions ; but considering questions of meaning, which deal with the rationality beneath this phenomenon, considered in its objective manifestations as well as in its meaning

[17] "Un système symbolique fondé sur une conception dualiste du monde (avec) des relations d'alliance et d'échange avec les êtres surnaturels censés gouverner les êtres naturels dont dépend sa subsistance (…), (avec) la nature qu'il traite en partenaire, ce qui réclame de sa part un art personnalisé ; cette fonction, régulière, lui confère une place centrale et fonde le caractère totalisateur du chamanisme dans les sociétés dites, pour cette raison, chamanistes" (Hayamon [1990]. See also Perrin [1995].

[18] Ricard [2000].

[19] The native languages spoken in this altiplano are quichua and aymara.

contents. Such a kind of research would be epistemological at the same time it is ethnological, and would be able to give original insights about the "universality of rationality", which is at the roots of the unity of human kind. An idea of the ur
shamanism is no more isolated, as relations exist between different shamanic societies, between shamans of various places, of them with the urban society, with christanism and african religions (giving rise to syncretisms), even with ethnological approaches through the mediation of conscious informers. Shamanism in this region shows a progressive acculturation, through modifications and adaptations, the modalities of which may reveal the role played by rational reflexivity from the shamans as well as from their interlocutors. Such moving circumstances may be favorable to catch rationality at work in the modification of representations[20].

A dialogue, about such questions, between the anthropologist and the epistemologist would be highly welcome, because it would possibly lead to new results and perspective, on shamanism and its «reasons», object of these inquiries, but also in contributing to widen the apprehension of human faculty of reasoning in its most diverse modalities. Rationality manifests itself under a variety of forms, depending on the cultures, on the representations and knowledge systems, and also on the diversity of the objects of knowledge. Some unity is present inside these various forms, which makes communication possible between them : similarly, history of ideas, of philosophy and of science have been effective in our understanding of the connections existing between religious representations and scientific knowledges.

Another example would be that of the parallel or convergent developments of objective (or positive) knowledges in different cultures taken at a given time in history and that are directly subject to comparison from our point of view of «downtime». I do not resist, at this point, to evoke what I have learned at one of the sessions of this Mexico XXI th International Congress of History of Science (the one entitled « Ciencia y tecnología en el México antiguo »), from the (rather fascinating) communication of professor Jésus Galíndo Trejo, about a possible ancient observation of an exceptional astronomical event by Teotihuacan astronomers at the beginning of the present era : an event dated from the Maya calendar, and registered in petroglyphs adequately disposed and pictured[21]. These petroglyphs represent concentric circles with two perpendicular diameters, rather frequent in all Mesoamerica, but concentrated with a rare intensity in a Teothihuacan town named Xihuingo.

According to Galíndo Trejo's analysis, it is possible to connect two by two the centers of such marking stones obtaining the directions of astronomical, solar or planetary, events ; among these pairs of glyphs, one emerges as exceptional, by the larger number of concentric circles, the related engraves with the drawing of a five-harmed star, a symbolic indication for an unusual brillance,

[20] Xavier Ricard, « Shamanic practices and shamanic representations in Southern Peruvian Andes. Research project », manuscript, dec. 2000, and private communications. I acknowledge enriching conversations I had with Xavier Ricard on occasion of his rare passages by Paris.

[21] The Teotihuacan culture, akin to Maya's one, was flourishing with an apogee from 200 to 600 AD, and have erected the famous pyramids of the Sun and the Moon (close to what would be the Aztecs capital, Tenochtitlan, now Mexico City).

and a date in Maya's notation ; the direction taken from the centers points toward a region of the sky higher than that of regular planetary events. Considering these data, Galíndo Trejo suggests that the event registered was well probably a supernova ; and it happens that a supernova in this direction, situated in the Scorpion constellation, had been effectively registered by Chinese astronomers in their catalogues for the year 393 AD, that corresponds to the date written down in the mexican petroglyph[22]. If the proposed analysis of the data is correct, and the fact thus confirmed, we would have a simultaneous observation and registration in two very different and, as far as we know, unconnected cultures, of the observation of a supernova in antiquity.

I am not able to judge whether the claim is fully fundamented or too much hypothetic, but, as Italians say, «si non é vero, bene trovatto». For it is at least plausible, considering the degree of advancement of Mesoamerican civilizations in astronomy at that period (they had observatories, a refined calendar, and there are reports that they even organized once, according to registers carved in stones, a meeting of astronomers coming from different regions and ethnies of Mesoamerica to unify their calendars[23]). And considering also that ancient Mesoamerican astronomers had probably no reason, similarly to Chinese ones, to be prevented from paying attention to the apparition in the sky of a new and very brilliant star staying there for several months. Their European contemporaries, on the contrary, where inhibited against such obervations by their conception, inherited from Aristotle philosophy and Ptolemeous astronomy, of unalterable heavens.

Despite our poor effective knowledge of precolombian astronomy, for lack of data, due to the destruction of many precious old manuscripts by the conquerers and their Inquisition, it is tempting to think of possible comparisons between the astronomies developped by the ancient peoples of, respectively, Middle East and Europe, China and America. Their naked-eye observatories and the observations collected of celestial events, their calendars, their calculations and predictions show, for those which we know, a strong common interest and a like ability to ascertain with precision astronomical facts : which, indeed, is to be referred to rationality, a widely shared rationality. But this «positive» or «objective» rationality, which is that one filtered by our conception of scientific thought, is, in the various cultures, differently but intrisically linked with and, actually, embedded in, other kinds of mental attitudes and beliefs (religious, astrological ones, etc.) and practices (technical practices, as for agriculture, and cultural habits, such as State bureaucracy in ancient China, ritual human sacrifices in the pre-colombian Mexican world, etc.). Such beliefs, habits and practices seem to have been present in all the primary and ancient stages of astronomy and they are, stricly speaking, inseparable from the corresponding «positive» rationalities, and they affect them in some way or other. And observation itself, that would seem to be a common faculty that transcends cultural differences (this faculty being ultimately referred to rationality), is also affected (remind the perfect

[22] Galíndo Trejo [2001], and oral exposition at the Congress.

[23] On Mayas achievements on astronomy and calendar (which developed fully between 200 and 900 BC), see Thompson [1958] ; and on Maya influence on other american indian cultures, see Radin [1935], chap. 2. These are my readings, clearly not up-to date.

celestial sphere of the Greeks just evoked) by the theoretical, metaphysical or religious conceptions and beliefs, and therefore displays also differences.

Other types of cases to be fruitfully considered for our inquiry about the forms of rationality are those of men of science from different cultural horizons who come into processes of interaction, exchange, and even dialogue, witnessing convergent intellectual and rational grounds of their thoughts, despite the cultural differences. Of such a kind was the encounter of European Jesuits with Chinese mathematicians in 17 th century : from both sides there recognized that they were speaking of the same field of knowledge (altough a very abstract one, such as mathematics)[24]. Such also, and even more striking, were the reciprocal travels of the French astronomer Le Gentil in India between 1761 and 1770, and of the Indian noble Mirza Abu Talib Khan in France and Europe between 1799 and 1803, as reported by Dr Irfan Habib in another session of this Congress (that on « Changes in interpretation and conceptual contents »)[25]. In these we acknowledge also an intellectual feature that favours the recognition of common grounds for rationality : the mind-openness of both travellers, and their desire to know what the other culture had that was missing in their own. In other words, they consciously and wellwillingly prepared their minds to enlarge their abilitiy to know and to understand, through widenings of their own rationalities, by meeting and confronting with the other.

3. CONSIDERING SCIENTIFIC FIELDS IN MODERN AND CONTEMPORARY SCIENCE

Then we come to other kinds of cases, dealing this time with scientific fields in modern and contemporary science. Let us first mention the diversity of the «*episteme*» of each of the various sciences as they have been elaborated. Each of these «episteme», characteristic of a specific domain of knowledge or scientific discipline, delimits the ways of reasoning and of acting inside the field considered : mathematics, physics, chemistry, biology, astronomy, social sciences… Despite the different and specific characters related to the corresponding objects, fields, methods, etc., these scientific domains have in common a number of general and alike features of their own rationalities, and this link is strong enough to allow us referring to them as *science* in general.

Consider also the constitution of scientific disciplines at the time when knowledge practices and contents began to be separated into *proto-sciences* on one side and *science* on the other. This happened by the imposition of scientific requirements corresponding to a set of norms outside of which any propositions on knowledge were not considered anymore as science but either as error either as pseudo-science.

A strong example is the progressive constitution of modern physics that started in XVIII th century (theoretical and mathematical, as well as experimental physics). The middle of that century was the marking moment when this scientificity requirement was formulated in a definite way, on occasion of the

[24] Jami [1992, 1996].

[25] Habib and Raina [2001], and the oral exposition by Irfan Habib at the Congress.

process of mathematization of physics, and of the setting up of precise observational or experimental rules to be confronted with the theoretical statements. The mathematization of physics began with mechanics, the science of the motions of bodies *in space* and *through time*, these being continuous quantities with a mathematical expression. The study of motion, from local and instantaneous changes up to global trajectories and laws, entailed the need, further than the usual geometry, of differential and integral calculus, the use of which required a considerable training and professionalization.

Euler, Clairaut and d'Alembert defined, in the line of newtonian physics, a new physico-mathematical «analytical» style for physics, in the domain of mechanics of solids and fluids, and of astronomy. By doing so, they determined a «no return» motion that, from then on, at least in this domain, excluded as an effect outside of science all other approaches, purely qualitative and often fancyful[26]. They were at the same time fixing implicitly the conditions that would have to be filled in order to open and elaborate new scientific fields for physics, which occurred in the next century, with optics, electromagnetism, thermodynamics and chemistry. These conditions correspond to a new turn for scientific rationality, where the physical concepts and magnitudes had to be conceived through their mathematical expression, and their mutual relationships were to be ruled by physical principles adequately choosen (enunciating generalized founding physical properties).

Our last kind of cases will be that, today quite commonplace, of changes occurring or manifesting their necessity inside a given established field of scientific knowledge. The need for such changes comes from experimental or theoretical considerations of a definite and precise nature. The change in knowledge, be it already realized or be only its necessity ineluctably announced from some unsuperable inconsistency at the present state, reveals the presence hereafter of elements of knowledge that were absent previously. It is some «*novelty*» that manifests itself in such situations, that is to tell something previously unknown and even unsuspected that is in the process of being known. «Novelty» is often incorporated into knowledge, in the beginnings, in negative or blue-print, and it demands, for being fully assimilated and recognized, for being known, to be made *intelligible*. «Novelty», for this, not seldom requires reorganizations of the existing knowledge, which implies most often *modifications of rationality* itself. Let us quote two examples of such processes.

Let us consider first the newtonian concept of (instantaneous) gravitational attraction at a distance, which imposed itself in order to give account of the laws governing the solar and planetary system, although it was not explainable in terms of any previously known physical knowledge (of the type of mechanical actions of contact). It is adequate here to refer to d'Alembert's epistemological analysis of the concept of attraction, elaborated some sixty years after Newton's *Principia* and published in Diderot's and d'Alembert's *Encyclopédie*[27]. This analysis can be summarized as the recognition of a rational necessity, although not reducible in known terms, and as a transformation of this

[26] See Gingras [2001], Paty [2001e].
[27] D'Alembert, entry « Attraction », *in* d'Alembert and Diderot [1751-1780], vol. 1. See Paty [2001 a, d].

«empirically originated» concept, into a rational principle of explanation for the motion of celestial bodies. So to speak, the rational explanation was not to be looked for in the past knowledge, but it was let to be found in a proximate future knowledge, which would emerge from the theoretical construction in which it was presently incorporated. Its mathematical form (the inverse square of distances) offered itself as a tool permitting to obtain the adequate theoretical relationships between the dynamical quantities that would prove adequate (in the case through calculations of the three-body problem for the Sun and planets). This new view, as explicited by d'Alembert, allowed to understand the concept of attraction-at-a-distance that was previously unthinkable through its dynamical function in the theory of mechanical astronomy. We can rightly call this process of making intelligible the whole system of attraction-mechanics-astronomy a modification (in the circumstance, an extension) of the physico-theoretical rationality.

The second example is more recent, as it deals with the question of the interpretation of quantum theory. This theory, aimed initially at phenomena that escape direct perception like atoms, radiation and elementary particles of matter, makes use of abstract concepts, got from the hamiltonian formalization of mechanics and classical physics, such as that of «state function» (defined in mathematical Hilbert space, and submitted to the «principle of linear superposition») and «dynamical variables operators» (also mathematically defined) acting on these state functions. These concepts or quantities give account, through the application of the mathematical formalism, of the specific behavior of quantum phenomena and systems. But their physical meaning has been considered questionable, as these theoretical entities do not correspond directly with the more common ones that are measured through the man-sized experimental devices and are of a classical type.

The theoretical (mathematical) quantities of the «formalism» are put in correspondence with the observed experimental results in an indirect way, by adding to their mathematical form an «*interpretation*» (in mixed physical and philosophical terms, the so-called «orthodox» interpretation, or Bohr's «complementarity conception»). By itself, this way of making quantum phenomena intellligible represented already a change in the usual way of rationalizing physics, and can be considered as a change of rationality : a strong change indeed, maybe a too strong one, because it modified drastically not only the theoretical conceptions of physics, but nearly all the underlying meta-theoretical conceptions, including general philosophy of knowledge itself (about reality, observation, understanding…).

Other ways of getting intelligibility of the quantum domain can be looked for, that would be less costly on the whole for our general conception of knowledge and for our theoretical understanding. For example, we could choose an interpretation of quantum theory that would give privilege to the follwing consideration : physics prefers, if we dare say, to find the meaning of its statements inside its own theoretical system, avoiding, insofar as it is possible, to borrow external intelligibility statements. It happens that to do so is possible by simply admitting that the theoretical, mathematical, abstract quantities of the «formalism» can be consitently considered as having a direct physical meaning, that of representing theoretically the quantum system considered. As a matter of

fact, all specific quantum properties are given from these (in particular the ones exhibited recently for individual quantum systems :interference, entanglement or local non-separability, etc…), and they are therefore, more than any other ones, physically significant. One would then be in right to afford a direct physical meaning to state vectors and operators as representing directly quantum systems, for they bear the relationship properties, which is characteristic of magnitudes or quantities in general[28].

This new understanding would suppose to enlarge the usually admitted definition of a *physical quantity*, restricted generally to numerical variables and functions, by allowing it to embrace as well the more complex mathematical forms of the quantum theoretical quantities. Such an extension of the meaning of *what a physical quantity is* considerably simplifies the problems of interpretation, as I have argumented elsewhere[29]. Clearly, it corresponds to a modification of rationality when considered for quantum physics, and actually to an *extension of rationality*, as it provides a larger basis for understanding both quantum and classical physics and their relationships (the passage from the one to the other domains). Here again, changes (as it is, widenings) of rationality makes possible a fuller and deeper intelligibility.

4. RATIONALITY, ON THE WHOLE…

From these considerations let us draw, provisionally, in a few commented sentences, some unformal elements of conclusion, that appear actually related to the interest, for further investigations, of considering a «history of rationality», of the diversity of its forms and the universality of its function, of its changes, its confrontations and, as it seems, its widenings and growth.

Rationality makes communication possible. What we have called «different rationalities» have in common their efficiency in symbolic representations, their function of intelligibilty, and their ability to favour communication, inside a given group or culture (for a given rationality), as well as from one system of rationality to another one. In the last case, communication might be somewhat difficult in particular situations, but one can, at least, think of and learn how to come to such a communication : many endeavours and experiences, along the history of societies and cultures, witness that it is possible and has been effective.

Assimilating the empirical. In order to enlarge and deepen the access to the empirical world one needs transformations and widenings of rationality, as many examples of the use of mathematics in physics have attested, especially since XVIII th century.

Intelligibility depends on rationality. The empirical let itself be read and assimilated according to a rational scheme in order to become intelligible. In other words, intelligibility is not unique but depends of the type of rationality associated with it.

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[28] For a general analysis of the notion of magnitude or quantity, in mathematics and in physics, see Paty [2001c].
[29] Paty [1999b].

Comparing rationalities. What makes a hierarchy of the rationalities for a given field of knowledge is their respective capacities to be open to the necessity of changes, in particular through communication.

Rationality is doomed to grow. Rationality in knowledge processes, as well as in other domains of human thought and activities, is doomed to change, and in particular, concerning science, to extend. Reason is a human, mental, capacity that can grow without ceasing to be reason, and by continuing to be an homogeneous function of the mind. It nutrishes itself from the empirical world, as well as from scientific practice, and from exchanges and assimilations of other elements of rationality of a different kind, merging them into a more comprehensive rationality.

(México-Tenochtitlán, july 14th, 2001.)

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